STATUS AS OF OCTOBER 2003 OF THE FRENCH UMo GROUP DEVELOPMENT PROGRAM

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ABSTRACT

The French program for the development of UMo fuel takes benefit of the support of 5 partners acting intensively in the framework of MTR (CEA, CERCA, COGEMA, Framatome-ANP and Techicatome). The aim of the French UMo Group program is to deliver a high performance with reprocess ability LEU UMo fuel qualified for a wide range of Research Reactor, and covering the expected needs for MTR next generation. The program takes into account the milestone of 2006 induced by the US return policy of spent fuel.

The French UMo Group program that has been launched in 1999, has already produced significant technical issues based on the fabrication of full sized fuel plates and various irradiation experiments. This program is dedicated to the characterisation and the validation of U-7%Mo with a density up to 8 gU/cm^3.

This paper describes the status of the French UMo program as of end of 2003 and recalls its specific features that covers manufacturing of full size plates, irradiation, reprocessing tests and fuel characterization. Since the last RERTR meeting in November 2002, significant achievements have been obtained. Recent evolution of the FUTURE and IRIS 2 experiment is presented in addition of the completion and distinctive contribution of IRIS 1 examination and interpretation. A synthesis of the next steps of the French UMo Group program is presented, with the corresponding time schedule.

1. Introduction

In the frame of LEU conversion of research reactors, and taking into account the choice of UMo [1] to achieve high uranium density (higher than 6gU/cm3) and allow better reprocess ability, the French UMo Group was formed and started its development program in 1999. It implies closely five partners acting intensively in MTR field : CEA for in-pile experiments, post-irradiations examinations and code development, on the R&D side, and four AREVA's companies on the industrial side : CERCA for manufacturing aspects, COGEMA for reprocessing aspects, Framatome-ANP and Technicatome for other engineering aspects. These companies present a leading offer covering MTR fuel supply and reprocessing, MTR engineering and services.

The objective of the French UMo fuel development program is to contribute to the qualification of a high performance UMo fuel with an uranium density up to 8 $gU.cm^{-3}$ in order to (1) make possible the conversion to LEU of reactors that still require HEU, (2) provide a LEU fuel with an available back-end solution as an alternative for reactors currently using U_3Si_2 fuel, (3) and make possible the design of new high-performance LEU reactors.

The French program has two specific features. It is performed mainly on full-sized plates, and all different aspects regarding the whole fuel cycle are considered : manufacturing aspects, irradiation behaviour, fuel characterization and code development (in cooperation with ANL), and reprocessing validation.

The objective of the French UMo Group is also to consider the milestone of May 2006 induces by the deadline of the US return policy of spent fuel. That implies a lot of constraints as regards the time schedule and the corresponding technical options.

2. Manufacturing aspects

The manufacturing of the UMo plates at CERCA was described in [2]. In a first stage the UMo powder was produced by grinding. The powder so produced contained a large number of small particles having a large surface-to-volume ratio. For more recent experiments (FUTURE and IRIS2, see below), atomized powder, with spherical particles, are used.

For UMo plate manufacturing, CERCA used its proprietary advanced process, early developed for the highly loaded U_3Si_2 plates with densities up to 6 gU cm^{-3}. The volume fraction of UMo fuel particles is always about 50%, but the porosity in the meat depends of the powder used : this porosity is greater than 10% for grounded powder, and lower than 4% for atomized powder. The fuel meat density is slightly greater than 8.0 g cm^{-3}. Fuel-plate inspection (based on micrographs, X-ray, and ultrasonic controls) indicated that the plates conformed to the specifications [10] [11].

The first UMo plates have been supplied by CERCA since 1999 and were dedicated to IRIS1 and UMUS experiments. In 2002, CERCA was able to produce a new set of full-sized plates and one lead test element for R2 in a very short time. This remarkable result shows the good progress made by CERCA and allows a continuation of the development program in accordance with the expected time schedule. This unique experience is supported by a sustained R&D effort as regards the manufacturing aspects. That includes for instance the development of the numerical simulation of rolling (see [13]).

3. Irradiation experiments on full-sized plates

The French irradiation Program on full-sized plates is based on four experiments with increasing surfacic power and clad temperature (see Table 1).

The first experiment, named IRIS1, was performed in OSIRIS reactor on two UMo plates with ground powder and 19,75% enrichment. The maximum surfacic power at beginning of life was 120W/cm^2, and the maximum cladding temperature 75°C. The irradiation was maintained 240 days in the reactor to obtain an average burn-up of 50% (local maximum burn-up of 67%). The non-destructive and destructive examinations are complete at present (see [12]), and reveal a new understanding of the ((U-Mo)Al_x structure in the interaction layer. These results are of first importance. The IRIS 1 experiment validates the UMo behaviour up to the average burn-up of 50% with P_{max}<120W/cm^2 and Tclad < 80°C.

The second experiment, named UMUS, was performed in HFR reactor on four UMo plates with ground powder, two of them with 19,75% enrichment and the two others with 35% enrichment. The experiment was stopped at the end of second cycle (48 Full power days), due to the failure of a 35% enrichment plate. The explanation of the failure, due to a high operating cladding temperature and the associated thick boehmite layer, is presented in [8].

The FUTURE experiment in the BR2 reactor includes two UMo plates with atomized powder, and enrichment of 19,75%.The surface heat flux is up to 340 W/cm^2 and 130°C. These conditions are defined as envelope conditions, in order to investigate the limits of the fuel. This experiment was suspended after two cycles (corresponding to a maximum burnup of 28%) due the measurement of a local abnormal swilling. Destructive examinations were decided on one plate. They show that the corrosion is low and the cladding intact. Void in the meat are observed on swollen area. The examinations are still going on at SCK/CEN.

For the IRIS2 experiment the maximum surface heat flux is 230 W/cm^2, and the maximum clad temperature 110°C. The IRIS2 irradiation conditions are representative of the maximum standard conditions encompassing by the qualification domain. The experiment is in progress. After two cycles, the maximum burnup reached is 28%, and the measured thickness increase is about 25µm, that corresponds to a mean value of 2%. These results are very encouraging.

The table 1 below summarizes the main characteristics of these four experiments on full size plates.

Experiment	**IRIS1**	**UMUS**	**IRIS2**	**FUTURE**
Reactor	OSIRIS (Fr)	HFR (Holl)	OSIRIS (Fr)	BR2 (B)
Number of full-size plates irradiated	3	4	4	2
UMo powder	ground	ground	atomized	atomized
Enrichment (% ^{235}U)	19,75%	19,75% / 35%	19,75%	19,75%
Max surfacic Power at BOL (W/cm^2)	120	170	230	340
Max cladding Temperature (°C)	75	90/110	110	130
Coolant velocity (m/s)	8	8	8	12
Status of experiment	achieved	stopped	In progress	suspended
Number of irradiation cycles	10	2	$2^{(1)}$ / $4^{(2)}$	$2^{(1)}$
Maximum burn-up at EOL (% ^{235}U)	50	15	$28^{(1)}$ / > 50%(2)	$28^{(1)}$

(1) value reached
(2) objective for the final value

4. Reprocessing aspects

The central problem for most users of U_3Si_2 is the lack of an available back-end solution including reprocessing. As stated above, one requirement for a new high density fuel is that it can be reprocessed. A key feature of the French UMo program is that COGEMA, with La Hague plant as the main remaining facility for the reprocessing of research reactor fuels, is technically and financially involved in the UMo development to make sure that reprocess criteria are met. The reprocessing feasibility of UMo has been obtained in 1998. The internationally accepted specification for vitrified waste will be met. Research and Development are ongoing at COGEMA with technical support of CEA to confirm and adjust operating industrial process.

Tests on UMo irradiated full scale plates (coming from OSIRIS) are in progress. The objective is to validate the process that ensures a total dissolution of UMo plates into standard fuel dissolution solution, in order to be compatible with La Hague's Purex process.

5. Fuel characterization and code development

A great effort has been initiated as regards the fuel characterization. This characterisation has to be determined in a first step using non irradiated fuel inspection. That concerns : UMo alloy composition, density of uranium, powder granulometry, homogeneity, cladding thickness, fissile zone dimensions and thickness. Inter-cycle and post irradiation non destructive examinations are based on : gamma spectrometry for burn-up evaluation, power calibration and fission products mapping, with complementary thickness measurements. The final destructive examinations used metallographic analysis. All those measurements allow the definition of the proper physical laws applicable to the UMo behaviour, that cover : UMo / Al interaction, microstructure identification, thermal properties, mechanical properties. In addition to the physical models, numerical codes are required to determine the global behaviour of the fuel, combining the different aspects.

For that purpose, a close collaboration between CEA and ANL fuel experts has been developed during the last three years, starting first by a detailed exchange of PIE observations performed on RERTR experiments and French experiments and second by exchange of different fuel behaviour models and sharing the work of developing a common approach. The final objective is to obtain a large understanding of the in-reactor fuel behaviour.

During the past two years, ANL has put significant effort into modeling the evolution of the temperature of dispersion fuel plates during irradiation [11]. CEA started the development of a new thermal-mechanical code (called MAIA) early in 2001. The major models for fuel-matrix interaction and fuel-meat thermal-conductivity change developed at ANL have been implemented in the French code. These models are used to complete the interpretation of the F.UMo.G experiments. The have been widely improved when taking in account the UMUS and IRIS 1 results.

All these technical features will play an important role in the qualification of UMo.

6. Further steps of the French UMo Development program

The priority is to complete the IRIS 2 experiment and the following post-irradiation examinations at CEA LECA facilty. This experiment has already produced encouraging results after 2 cycles corresponding to at maximum burnup of 28%.

The examinations of the FUTURE plates and the interpretation effort will continue up to the end of this year. New characterization of the UMo-Al interaction is expected, with potentially an important impact on the physical models that are under development and used in the new MAIA code. The extension and

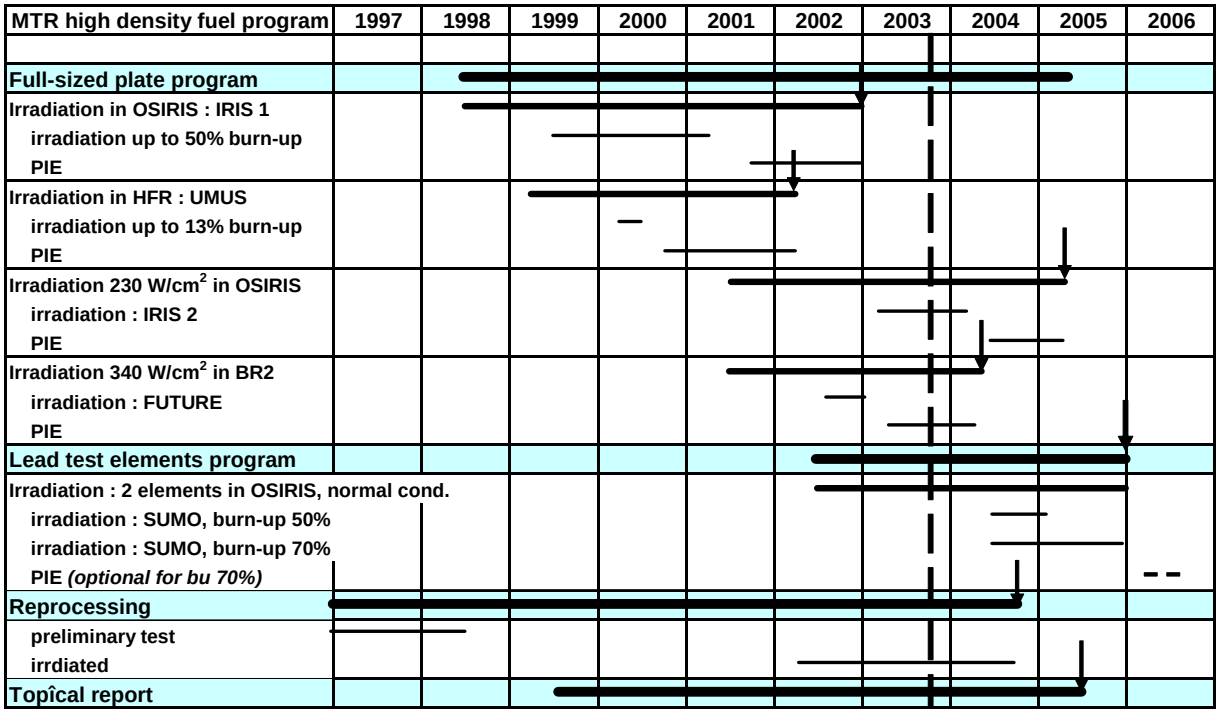
improvement of the numerical models will also take benefit form the completion of the IRIS 1 interpretation and characterization.

Significant results on irradiated materials are expected as regards reprocessing tests.

CERCA will focus its activity on the manufacturing of two OSIRIS lead test elements, taken into account the unique experience gained from the R2 lead test element fabrication. This new experiment called SUMO is envisaged through a close collaboration with ANSTO and ANL. One of these two elements is dedicated to reach a high burnup level of 70%. This irradiation will complete the experimental phase of the French UMo Group program.

7. UMo Development Time Schedule

The updated time schedule of the French UMo development program is presented below. A sustained effort is spent by the F.UMo.G to respect its objectives and the major milestones, and make the time schedule globally unchanged despite the incorporation the SUMO experiment in the program.



8. Conclusions

The French UMo development program has unique features at the present time. It is performed mainly on full size plates, and it takes into account all aspects regarding the whole fuel cycle : manufacturing, irradiation experiments, reprocessing tests, fuel characterization and physical models development. Technical results of first importance have been already obtained : in terms of UMo-Al interaction from IRIS 1, and potentially from FUTURE experiment, in terms reprocessing feasibility achived by COGEMA, in terms of manufacturing with the ability of CERCA to produce a large number of plates and the first UMo elements with an uranium density of 8g/cm^3. Encouraging results have already been obtained from the IRIS 2 irradiation with a maximum burnup of 28%.

As regards the deadline of 2006, the French UMo Group will be ready to manufacture UMo plates and assemblies and to offer a back-end issue through reprocessing to the MTR community. The F.UMo.G is determined to contribute to the UMo qualification through a reinforced international collaboration and will be able to supply engineering services for conversion and fuel management.

9. References

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